Shallow Water Diving – The NASA Experience

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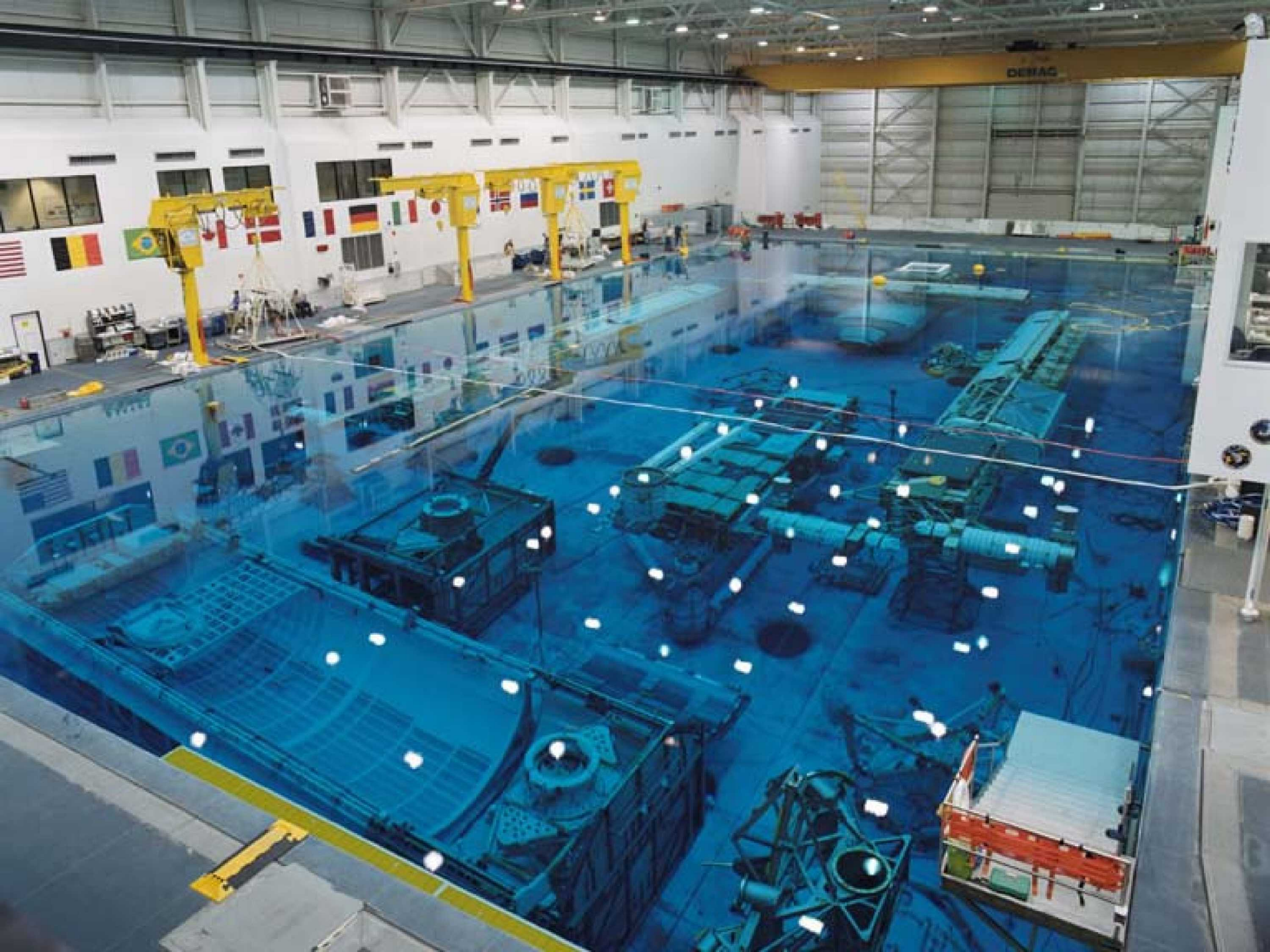
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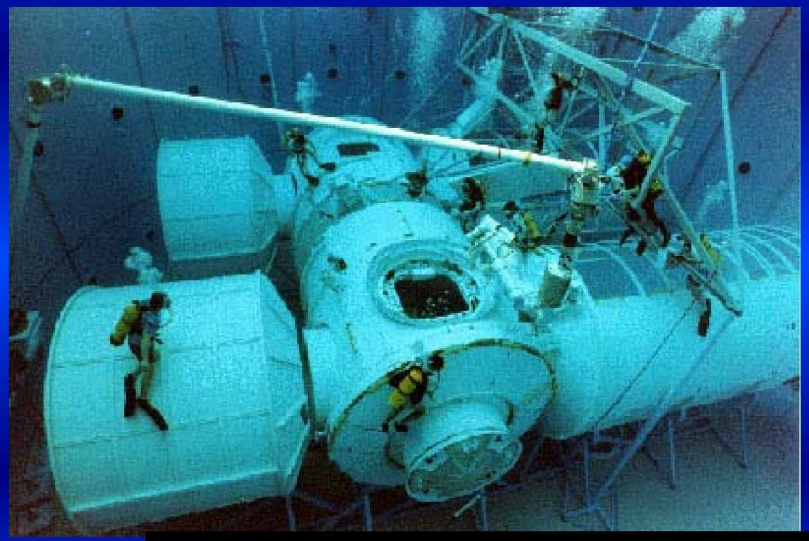
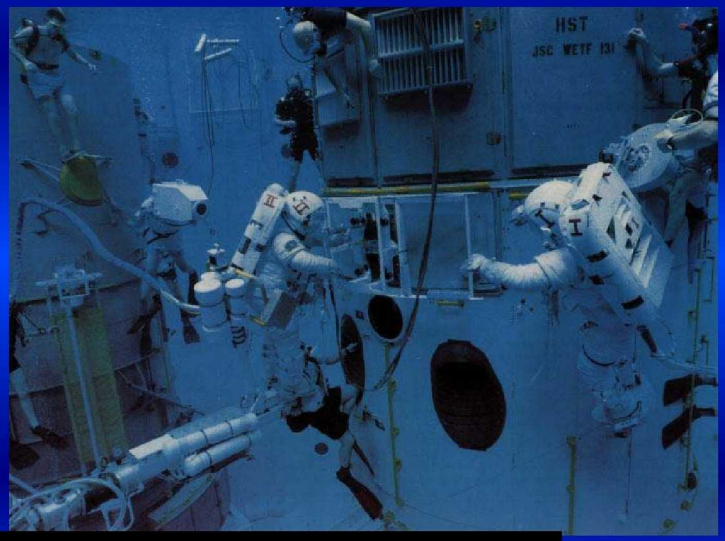
Standard NBL Dive

- Profile – 40 fsw for 240-390 min
- Breathing gas – nitrox (46% O_2)
- Dry suit (EMU) – pressurized to 4.2 psi
- Equivalent Air Depth of 23.2 fsw





*NBL - Neutral Buoyancy Laboratory, Johnson Space Center, Houston
*EMU - Extravehicular Mobility Unit (standard U.S. 'space suit')

Pressure

Force per unit area

ATA	FSW	PSI(G)	mmHg
1	0	0	760
2	33	14.7	1520
2.2	40	26.7	1672

ATA – Atmospheres Absolute
FSW – Feet of Seawater
PSI – Pounds per Square Inch
mmHg – Millimeters of mercury

Boyles Law

At constant temperature, gas volume is inversely proportional to the absolute pressure

- *As pressure increases, volume decreases*
  - *Breathing is a constant-volume process, the deeper the dive, the less breathing gas*
  - *Basis for treating arterial gas embolism (AGE), USN Table 6A*
- As pressure decreases, volume increases
  - Cause of pulmonary barotrauma
  - Greatest risk of injury occurs near the surface

Henry's Law

The amount of gas that will dissolve into a solution is directly proportional to the partial pressure of that gas

- Deeper the dive, greater the gas load for each tissue
- Upon ascent, gas in solution escapes to obtain equilibrium
- Too rapid gas escape results in Decompression Sickness (DCS)

Shallow Water Diving

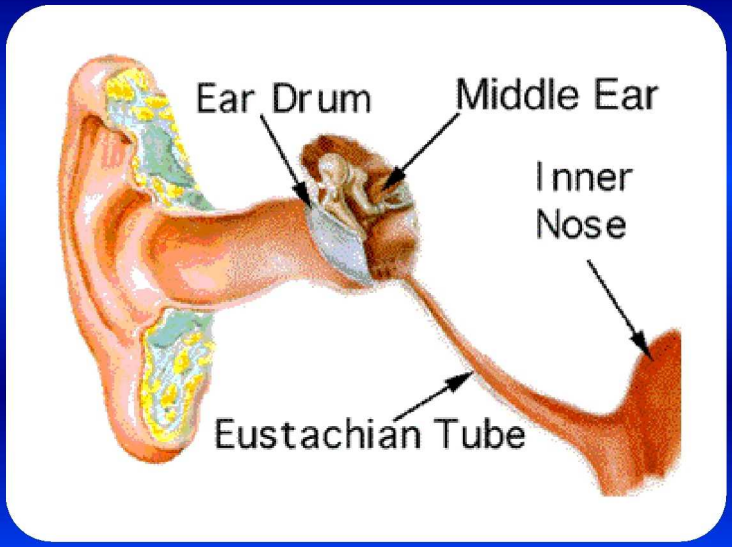
Adverse Physiologic Events

- Ear and Sinus Barotrauma
- Decompression Sickness (DCS)
- Pulmonary Barotrauma
  - Arterial Gas Embolism (AGE)
  - Mediastinal Emphysema
  - Subcutaneous Emphysema
  - Pneumothorax
- Oxygen Toxicity

Ear Barotrauma

- **Problems can occur on ascent or descent**
- **Causes:**
  - **External canal obstruction – cerumen, earplugs, tight-fitting diving hood, congestion, otitis**
  - **Inadequate middle ear pressure equalization – URI, congestion/allergies, inadequate equalization**

Unable to equalize if pressure >90 mmHg or 3.9 FSW

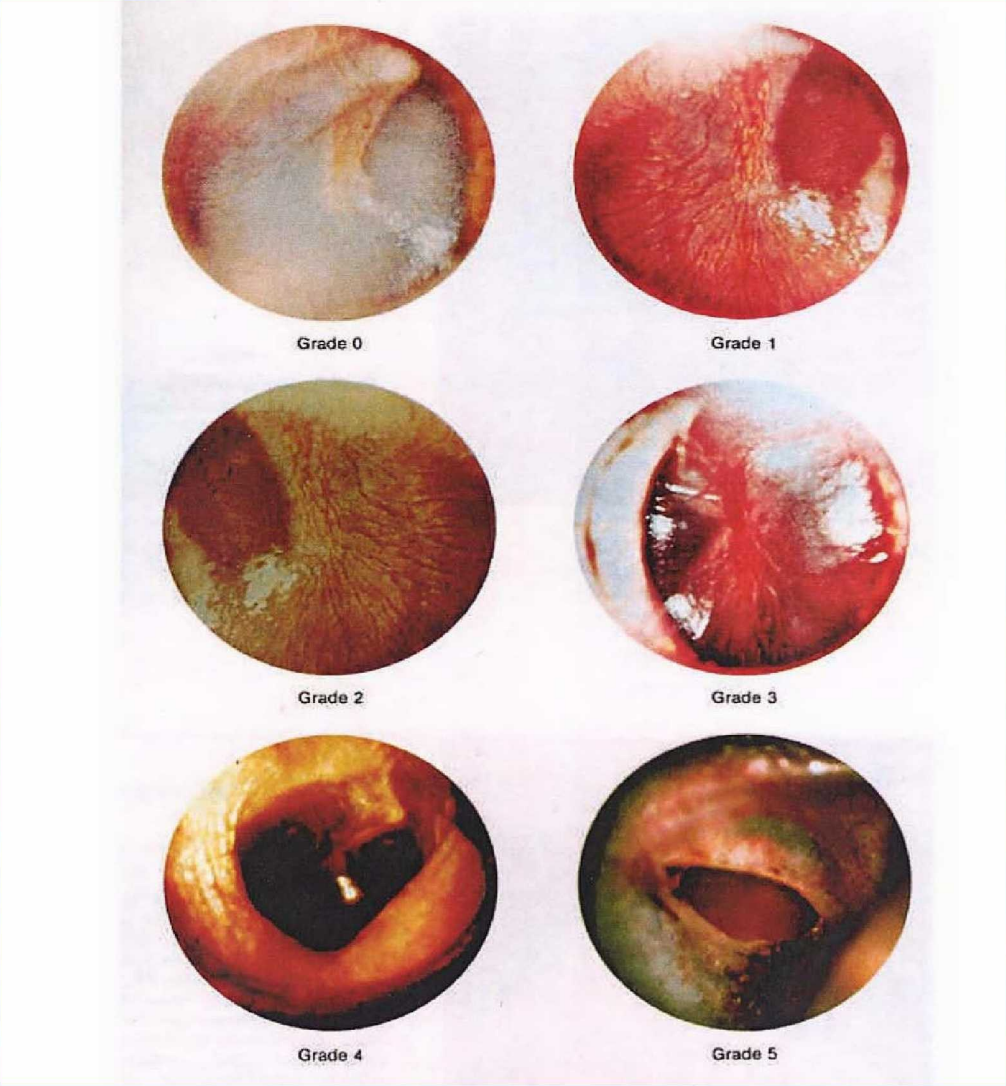


Ear Barotrauma

- Symptoms
  - Increasing pressure, then pain
  - Mild tinnitus and vertigo
  - Conductive hearing loss

- Otoscopic Exam
  - Grade 1 – TM retraction, diffuse erythema
  - Grade 2 – Slight hemorrhage within TM
  - Grade 3 – Gross hemorrhage within TM
  - Grade 4 – Bulging TM, fluid & blood in middle ear
  - Grade 5 – TM rupture, blood in canal

Ear Barotrauma



Ear Barotrauma

Treatment

- Treatment of pre-existing symptoms

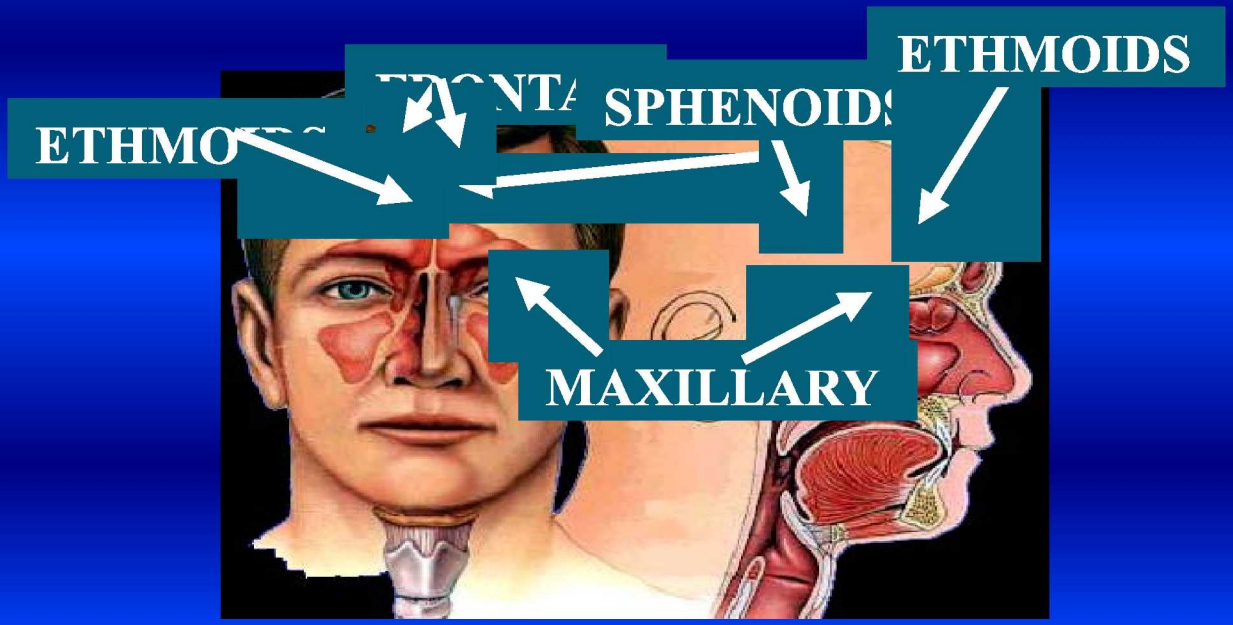
- Avoid further diving until:
  - Pre-existing nasal symptoms have cleared
  - Diver can equalize pressure at surface
  - Complete resolution on otoscopic exam

- Long-acting topical nasal decongestants (Afrin)

- Systemic decongestants (Sudafed)

Sinus Barotrauma

- **Problems can occur on ascent or descent**
- **Causes:** Inflammation and congestion of nasal mucosa, structural deformities, mass lesions
- Chronic sinus disease – allergies, chronic irritation (smoking, nasal sprays), obstruction, vasomotor



Sinus Barotrauma

- Symptoms
  - Pain – frontal sinus most common
  - Epistaxis
  - Upper teeth pain
  - Infraorbital nerve – decreased sensation
- Treatment
  - No diving until symptoms resolved (7-14 days)
  - Long-acting topical nasal decongestants (Afrin)
  - Systemic decongestants (Sudafed)

Mask Squeeze

Decompression Sickness

- Formation of bubbles in blood or tissue from dissolved inert gas (Nitrogen)
- Intravascular effects – platelet aggregation, leukocyte activation, increased cytokines, activation of complement, kinin and coagulation systems
- Rare occurrence in NBL divers

DCS Clinical Manifestations

Musculoskeletal – "Bends"

- Nitrogen bubbles in/around the joints
- Localized deep, dull, aching pain
- Primarily elbow, shoulder, hip, knee

DCS Clinical Manifestations

Cutaneous – Cutis Marmorata

- **Transcutaneous bubble formation**
- **Cutaneous vascular injury**
- **Symptoms: intense puritis, mottling or marbling of skin**
- **Precursor to serious DCS**

DCS Clinical Manifestations

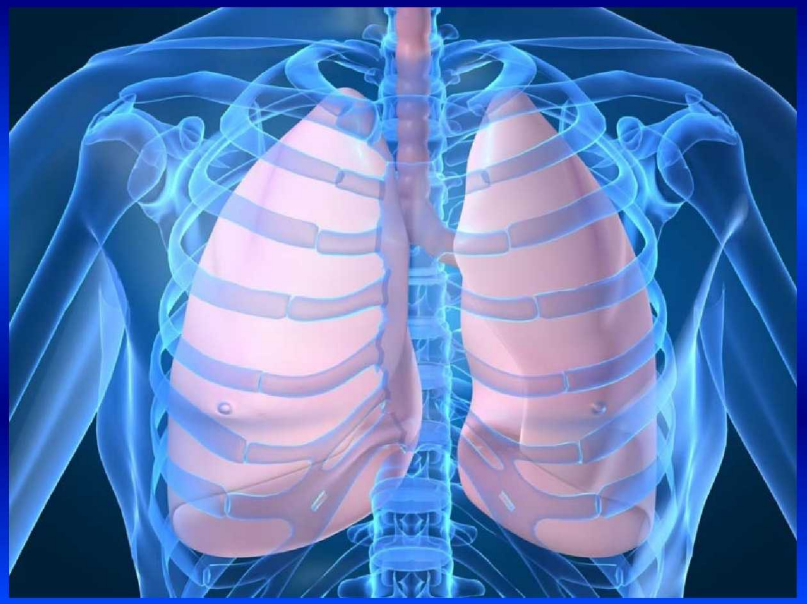
Neurologic – Spinal Cord, Brain

- Spinal Cord – muscle weakness, paresthesias, paralysis, sensory loss
  - May not follow typical nerve distribution
- Brain – headache, confusion, psychosis, LOC, profound fatigue, mental status changes

DCS Clinical Manifestations

Pulmonary – "Chokes"

- Nitrogen bubble obstruction of pulmonary vessels
- Requires severe decompression stress
- Occurs in 2% of DCS cases
- Symptoms:
  - Substernal burning pain
  - Paroxysmal cough
  - Shortness of breath
  - Aggravated by deep inspiration



DCS Clinical Manifestations

Vestibular – Inner ear

- Usually associated with deep mixed gas dives
- Symptoms
  - Vertigo
  - Tinnitus
  - Hearing loss
  - Nausea & Vomiting
  - Balance problems, “Staggers”

Decompression Sickness

Treatment

- 100% oxygen via aviator's mask or anesthesia mask
- Hyperbaric oxygen therapy
- IV hydration


NBL

Pulmonary Barotrauma

- Excessive intrapulmonary pressure & over expansion of the lungs
- Breath holding or local pulmonary obstruction
- Out-of-air, panic, unfamiliar with equipment
- Rare occurrence in NBL divers

Pulmonary Barotrauma

- Clinical Manifestations
  - Arterial Gas Embolism (AGE) – apnea, LOC, cardiac arrest
  - Mediastinal Emphysema – substernal pain, cough
  - Subcutaneous Emphysema – crepitus, hoarseness, dysphagia
  - Pneumothorax

- Treatment for AGE – CPR, 100% oxygen, recompression

Oxygen Toxicity

- Dependant on both the oxygen partial pressure and length of exposure
- Symptom onset accelerated by exercise
- Significant individual variability
- Acutely affects Central Nervous System (CNS)

CNS Oxygen Toxicity

- V – VISION; tunnel vision
- E – EARS; tinnitus
- N –NAUSEA
- T - TWITCHING; lips and facial muscles
- I – IRRITABILITY; includes anxiety, confusion
- D – DIZZINESS
- CONVULSIONS

Oxygen Toxicity

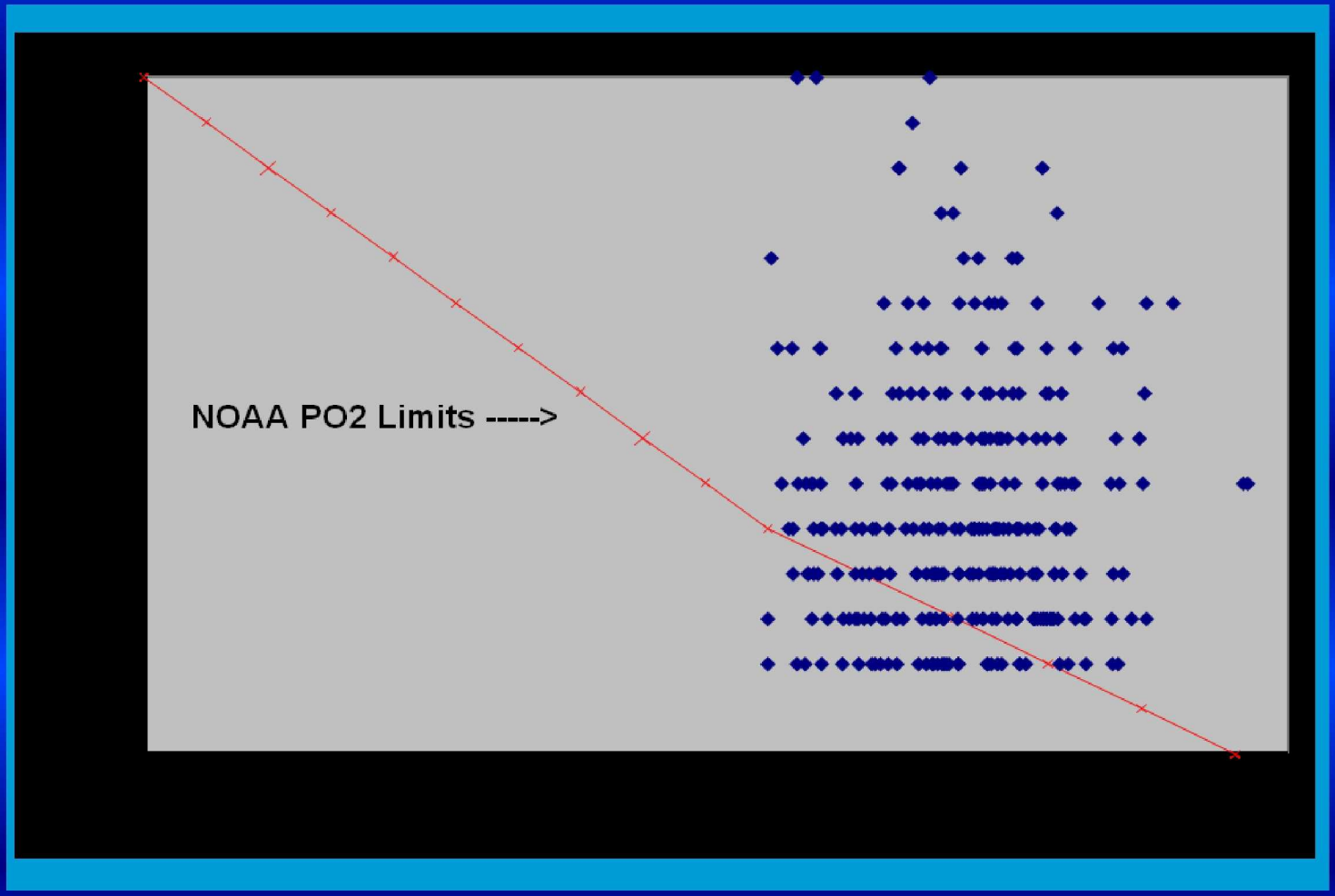
NOAA Oxygen Partial Pressure & Exposure Time Limits

Oxygen Partial Pressure in ATA	Max. Duration, Single Exposure (min.)	(hr.)
1.6	45	0.75
1.5	120	2.00
1.4	150	2.50
1.3	180	3.00
1.2	210	3.50
1.1	240	4.00
1.0	300	5.00
0.9	360	6.00
0.8	450	7.50
0.7	570	9.50
0.6	720	12.00

Oxygen Toxicity

- Astronaut training runs from 2004 – 2008
- 127 astronauts completed 2,231 runs for 12, 880 exposure hours
- 57% of runs exceeded 6 hours
- 30% of runs, average depth greater than 20 FSW
- No cases of decompression sickness or oxygen toxicity

Oxygen Toxicity



17% exceeded NOAA Limits

Pulmonary Function In NBL Divers

- 43 working divers at NBL
- 1-2 90 minute dives daily, 40 FSW max depth
- Gas-54% nitrogen/46% oxygen
- Questionnaire – diving hx, smoking hx
- NBL dive hours – NBL database
- Medical records – height, weight, PFT for pre-dive, 1yr, and 3yr

Pulmonary Function In NBL Divers

Results

- Ave 340 dive hrs yr 1; 904 dive hrs yr 3
- No significant impact of pre-NBL dive exposure and diving outside NBL
- Initial lung volume (FVC & FEV1) greater than predicted (104% & 102%)
- Significant increase for both at 1 year & 3 years
- Correlation between NBL dive hrs & improved FVC/FEV1
- No change in small airway function

Pulmonary Function In NBL Divers

Conclusions

- Working divers more fit compared to general population
- Improved FVC/FEV1 supports adaptation to diving
  - Increased work of breathing
  - Respiratory muscle training
- No adverse effects of shallow Nitrox diving on small airway function
- Unknown contributory effect of 46% oxygen breathing gas

Hypothermia

- Hypothermia occurs even in warm water
- Water has a thermal conductivity 24 times greater than that of air
- 85 degree water has a 14 degree temperature gradient
- Most heat is lost in the water from the head and torso, not the extremities
- Physical activity without thermal protection will decrease body temperature by convection

Symptoms by Core Temperature

CORE TEMPERATURE (F)	SYMPTOMS
98	COLD SENSATIONS, SKIN VASOCONSTRICTION, INCREASED MUSCLE TONE, INCREASED OXYGEN CONSUMPTION
97	SPORADIC SHIVERING SUPPRESSED BY VOLUNTARY MOVEMENTS, GROSS SHIVERING IN BOUTS, FURTHER INCREASE IN OXYGEN CONSUMPTION, UNCONTROLLABLE SHIVERING
95	VOLUNTARY TOLERANCE LIMIT, MENTAL CONFUSION, IMPAIRMENT OF RATIONAL THOUGHT, POSSIBLE DROWNING, A DECREASED WILL TO STRUGGLE

Countermeasures

- Limit dive time to 90 – 120 minutes
- Wear wetsuits with an adequate thickness & proper fit – hood, gloves
- Replace old, worn-out suits that have lost thermal protection qualities
- Warm shower, warm fluids and warm dry clothing between dives
- Exercise


Dive then Fly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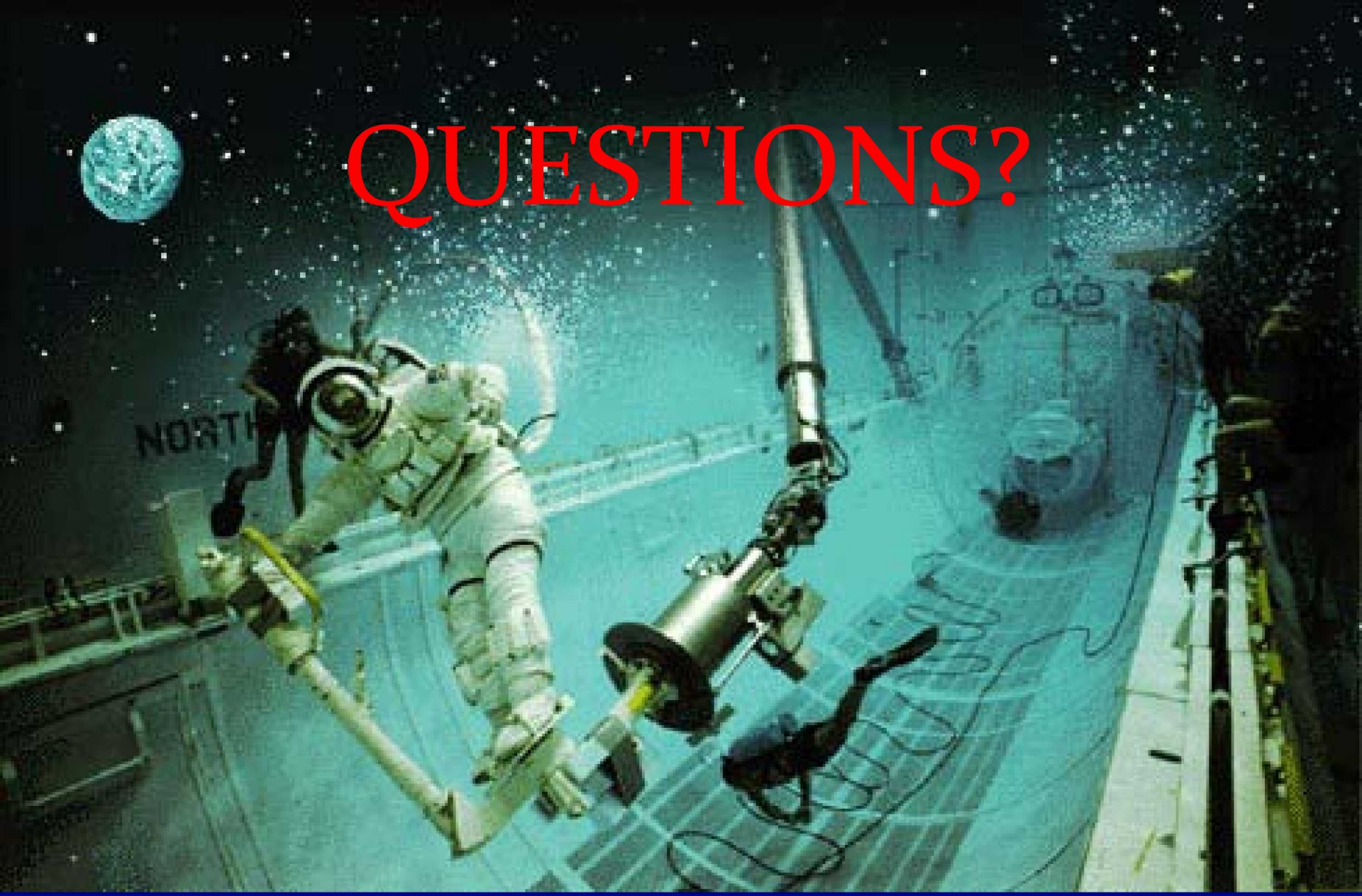
Flying after Diving

DAN Recommendations: Preflight surface interval of 12 hours for a single, no-decompression dive; and 18 hours for multiple dives per day or multiple days of diving.

NASA Recommendations: Cabin altitude 1,000 – 10,000 feet

EAD (FSW)	No-Deco Limit (minutes)	Duration (min)	Air SI (hours)	Oxygen SI (minutes)
0-20	No limit	1 – 60 61 - 100 101 – 400 >400	3 5 14 24	20 40 120 180
20-25	400	1 – 45 46 - 80 81 – 290 291 – 400	3 5 14 24	20 40 120 180


QUESTIONS?